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THE VOLCANICS OF THE MICHIGAMME DISTRICT, OF MICHIGAN (PRELIMINARY).

THIS name is given to a series of volcanic rocks occurring on the Upper Peninsula of Michigan, between Townships 42 and 47 N., and Ranges 30 and 34 W. They are included between the Paint (Mequacumecum) and Michigamme Rivers, and are intersected by their tributaries, the Fence (Mitchigan), the Deer, and the Hemlock Rivers.

Previous work in this area.—The chief interest in the area has been due to the occurrence of iron ores in the sedimentary rocks associated with the volcanics. The iron deposits first discovered in this region were those lying along the Paint River near Crystal Falls, just outside of the immediate area under discussion, and were briefly mentioned by Major T. B. Brooks in his report on the iron-bearing rocks of Michigan.[1] Apparently little attention was paid to the district for some time after this, except by the prospectors, who gradually advanced with their test pits to the north, until the deposits along the Michigamme to the northeast and at Amasa to the northwest were found.

In his report of work done on the Upper Peninsula between 1881–4, which has just appeared, Rominger[2] refers those iron deposits occurring along the Michigamme River in Township 43 N., Range 31 W., Section 4, and Township 44 N., Range 31 W., Sections 33 and 34, to the Huronian, corresponding to the rocks of the Quinnesec ore range, to which reference had been made in previous publications.[3] The volcanics were not recognized as such, but were called diorite.[4]

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[1] Geol. Sur. of Mich., Vol. I., Part I, p. 182, 1873: he writes, "Too little is known about the Paint River district . . . . to enable me to give anything of interest regarding its geological structure. The Huronian rocks are extensively developed there, and contain deposits of hard hematite ore."

[2] Geol. Sur. of Mich., Vol. V., p. 32, 1895.

[3] Ibid., Vol. IV., p. 82, 1881.

[4] Ibid., Vol. V., p. 37.

The mining district of Amasa is of quite recent development, and as far as I am aware no attempt has thus far been made to refer the deposits to any definite geological horizon.

During 1892, Messrs. W. N. Merriam and H. L. Smyth, with their assistants, were engaged in tracing out the iron-bearing formation in this region. Smyth worked in the northeast along the Michigamme River, and Merriam west of the Michigamme River and southwest of the Deer River. When their work was finished the two areas were not connected in the north by about twelve miles, and a narrow belt separated the mapped areas to the south.

During the season of 1894, I was engaged, with the assistance of G. E. Culver and S. Weidman, in completing this area, preparatory to extending the work into the Menominee iron district. Many of the facts of the field occurrence mentioned in the following article were observed and recorded by Merriam and assistants, and were subsequently verified by my own observations of last season in a different portion of the area, and by visits to localities in the areas previously surveyed.

Succession.—A résumé of the ascending succession is as follows: The area considered is oval in outline, about twenty-five miles long and twelve miles wide, extending in a N.W.-S.E. direction (Pl. I.) The center of this oval is occupied by an elliptical area thirteen miles long by three miles wide, of the oldest rocks of the district, consisting of granite and gneiss, cut by numerous basic dikes. This is surrounded by a quartzose limestone formation, with an estimated thickness of 1500 to 2000 feet.[1] In places the quartz almost disappears and we get a limestone. In other places we have an almost pure quartzite. The formation disintegrates very rapidly, and to this fact can probably be attributed the lack of outcrops over the greater portion of the area which it is supposed to underlie. Overlying the limestone we find, both to the east and west of the ellipse described, a great series of volcanics with an average thickness of about 3000 feet. Their greatest development is to the west of the ellipse, where the average thickness is 4000 feet. It appears probable that these two areas

[1] H. L. SMYTH: Relations of the Lower Menominee and Lower Marquette Series in Michigan. Am. Jour. Sci., 3d Ser., Vol. XLVII., p. 217, January 1894.

are connected around the ellipse both to the north and south, forming a belt completely encircling it. The volcanics are in turn enclosed by a zone of sedimentaries, for the most part quartzite and slate, which is throughout characterized by the greater or less amount of iron which it contains. It is known as the Michigamme jasper, from its typical development at Michigamme

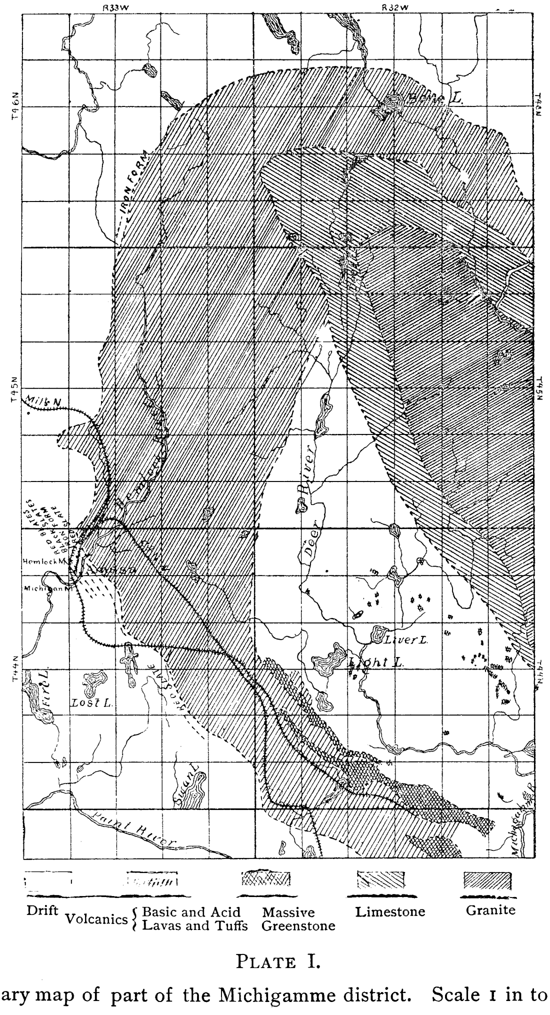

PLATE I.

Preliminary map of part of the Michigamme district. Scale 1 in to 4 miles.

Mountain.[1] Test pits are common where it outcrops, and at Amasa it contains iron in quantities sufficient to be mined. This series is also characterized by its marked magnetic properties. It was chiefly due to this property that it was found possible to connect the widely separated outcrops by means of the dip needle and of the dial compass.

The entire district is heavily covered with drift, showing in many places beautifully developed glacial topography. This mantle conceals so much of the country rock that the outcrops are very scarce, thus very greatly increasing the difficulties of the geologist.

Owing to the incompleteness of the work the structure of the area and the correlation of its rocks will be left for a future report. It can be stated, however, that the volcanics are of Huronian age.

Volcanics.—Those discussed in this paper lie in general to the west of the Archean core, and between Bone Lake on the north and Crystal Falls on the south. They are the rocks which predominate in, and are by far the most characteristic for, this district, the sedimentaries playing only a very subordinate rôle. The belt in which they are found varies in width from three-fourths to four and one-half miles. The apparent enormous thickness which this would give to the series in the widest part of the belt, since the dip of the rocks is about 75°, has been greatly increased by the minor crumplings and thrusts to which the series has undoubtedly been subjected. The very considerable thickness may be partly explained by supposing the volcanics to have accumulated in the immediate proximity of the vents from which they were ejected. If we accept an average thickness of 4000 feet, we will probably not overestimate it.

Since the flows are all now on edge, and erosion has left only isolated fragments of flows and accompanying tuffs, it is only possible to study them in cross section. Owing to this fact the topography is very rough, the elevations in most cases corresponding to the massive rocks, though thoroughly consolidated breccias form some of the highest hills. That these rocks are true volcanics could not be doubted for a moment by any one seeing them *in situ* or even in hand specimens. They exhibit the vesicular character and flow structure of modern lavas, and interbedded with them we find great masses of breccia and tuff, composed of dense and scoriaceous fragments of rock similar in appearance to the rocks of the lava flows. A fact to be noted is that remarkably few undoubted dikes have been observed. This may be due to some extent to the disposition of the strata.

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[1] Loc. cit., p. 217.

Both basic and acid igneous rocks are represented in the Michigamme district by lava flows and pyroclastic deposits. The basic volcanics comprise those altered pre-Tertiary equivalents of the basalts and andesites known as melaphyres and porphyrites. In the following pages they are called apobasalts and apoandesites. The acid rocks include originally holocrystalline porphyritic rocks, quartz porphyries, and devitrified equivalents of the rhyolites, which are here called aporhyolites.[1]

The apobasalts are by far the most common of the volcanic rocks. Their colors are various shades of green, dark olive-green prevailing. Upon weathering the green rock is usually covered by a thin crust, in which gray, brown, and even pinkish tints prevail.

The lavas vary in coarseness from dense aphanitic rocks to those which are medium-grained. No coarse-grained rocks are found among the interbedded flows and tuffs.[2] Some of the most characteristic volcanics are fragments in the pyroclastics. The most constant volcanic characteristic is the presence of a well-marked amygdaloidal structure, the rounded or more less irregular shaped amygdules ranging from those of almost microscopical size up to others larger than a pigeon's egg. Some of the rocks are so full of these vesicles as to be truly scoriaceous.

[1] F. BASCOM: The Structures, Origin, and Nomenclature of the Acid Volcanic Rocks of South Mountain. JOURN. GEOL., Vol. I., No. 8, p. 828, Nov.–Dec. 1893.

[2] In the southern portion of the area occur great continuous masses of coarse-grained rocks, which are undoubtedly closely related to the volcanics. At the present stage of the investigation it is, however, undecided just what this relation is. It is presumed that they represent great fissure flows, with which eruptive activity here began, and which were subsequently followed by the extrusion of the thinner lavas and ejection of the lapilli and ashes forming our present breccia and tuff deposits. Their general distribution is shown on the accompanying sketch map, Pl. I.

Thin sections of the rock show a characteristic ophitic structure, with in places a flow structure around the amygdules brought out by the feldspar microlites. The angular interstices between the well preserved lath-shaped crystals are filled by irregular pieces of fibrous green hornblende, with here and there epidote, zoisite, less chlorite, and grains of titanite, the result of the alteration of the original augite and titano-magnetite, and also of any original vitreous base which may have been present. The presence of a base is indicated by the presence of chloritic material between some of the feldspars, seemingly the alteration product of the base in which the crystals were imbedded. Moreover the sharply bounded walls of the amygdules may indicate the former presence of glass.[1] Olivine has in no case been observed. The feldspar is very fresh, only beginning to become slightly turbid through development in it of a few grains of epidote and flakes of chlorite. Rarely does any original magnetite remain, and in such cases the rock is very noticeably darker.

Apoandesite.—The apoandesites include those rocks which, while intimately associated with and very closely related to the apobasalts, differ from them in their porphyritic habit, having labradorite as phenocrysts.

In thin section the large automorphic phenocrysts of slightly altered plagioclase lie in a very fine grained matrix, composed of long slender feldspar microlites separated by crystals of magnetite,—though in most cases it has entirely disappeared,—and the alteration products of the original augite and base, fibrous green hornblende, epidote, zoisite, chlorite, and brownish grains of a mineral which has a higher single and double refraction than the epidote, and is presumed to be titanite. Measurements made against the twinning plane of the plagioclase phenocrysts give an average extinction angle of 25°, indicating the feldspar to be labradorite.

The character of the microlites I have not been able to determine with sufficient accuracy. The alteration which most of them have undergone makes the task of searching for suitably oriented and sufficiently fresh sections upon which to make measurements an exceedingly tedious one. The rocks frequently show a flowage structure caused by the parallel arrangement of the microlites around the phenocrysts and amygdules. The minerals of the andesite have suffered the same changes as those of the basalts. Andesitic fragments are also very common in the tuffs, although in no place do we have a true andesite tuff or breccia.

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[1] J. J. SEDERHOLM: Studien über archæische Eruptivgesteine aus dem südwestlichen Finnland. Tsch. Mit. XII., p. 113. 1891.

As is seen from the description of the freshest and most characteristic of the basic volcanics, the mineral constituents have undergone very far reaching alterations, the result of which has been to produce most commonly epidote, zoisite, fibrous green hornblende, chlorite, and less quartz, feldspar and calcite. More advanced alteration results in rocks very similar to the basalts and andesites as described above, in which, however, the feldspar crystals are replaced by chlorite and epidote, the feldspar shapes being retained. In such cases the ophitic structure shows nicely in ordinary light, but between crossed nicols the feldspars break up into aggregates of chlorite and epidote, completely concealing the characteristic structure of the rock. The very fine grained lavas undergo the same alteration, producing a very tough light green rock which does not show at all the structure of an eruptive rock, as they are frequently found free from amygdules. In the very fine grained rocks the production of so much epidote and titanite in minute grains, by their high single refraction, causes the rock to appear almost opaque in thin section.

In addition to these changes, which have been for the most part merely the replacing of one mineral by another, the rocks have been subjected to considerable pressure and shearing, which have in many places given them a more or less perfect schistosity. In such cases the flattening of the amygdules is especially noticeable.

The amygdules are filled by nearly the same minerals as those which occur secondarily in the rock mass itself. Arranged in order of frequence of occurrence they are as follows: Epidote, zoisite, chlorite, quartz, calcite and feldspar. The nonoccurrence of zeolites is very noticeable, since they are so common in the altered modern basalts, and also occur in basalts as old as those of South Mountain[1] and of Keweenaw Point.[2]

The amygdules usually stand out well from the body of the rock when filled with infiltrated products or when weathering has left them empty, giving the rock, in the first case, from a short distance, the appearance of porphyry, in the second, a decidedly scoriaceous look.

A columnar structure so common in the modern equivalents of such rocks is noticeably absent. A spheroidal structure, however, having the same appearance as that described by Lawson,[3] Williams[4] and also by Cole[5] and Gregory,[6] is quite common in the lavas. It was in no case observed in the fragmental deposits.

The breccias and tuffs.—Flow breccias formed of angular basalt fragments imbedded in a matrix of the same material are found, but since they preserve the main character of the ordinary basalt flows which have just been described, they will not be discussed in the following passages. The pyroclastics are very common and quite characteristic, the characters of the beds being best shown on the weathered surfaces. On these the light grayish green fragments of varying size and more or less angular shape stand out well from the brownish red matrix. A fresh surface shows the fragments to be light green, and the cement a darker green. The fragments vary in size from bowlders to minute ones which fill in the interstices between the larger ones and thus serve to make the mass compact. They are for the most part not amygdaloidal, but very dense, although those which are amygdaloidal and even scoriaceous do occur mixed with the dense fragments, and in places equal them in quantity. The basalt and andesite appears to be equally well represented in the pyroclastics.

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[1] G. H. WILLIAMS: The Volcanic Rocks of South Mountain in Pennsylvania and Maryland, Am. Journ. Sci., 3d Ser., Vol. LXIV., p. 491, 1892.

[2] RAPHAEL PUMPELLY: Paragenesis and Derivation of Copper and its Associates on Lake Superior, Am. Journ. Sci., 3d Ser., Vol. II., p. 188, 1871; also Geol. Sur. of Michigan, Vol. I., Part II., pp. 19–46, 1873; Geol. of Wisconsin, Vol. III., p. 31, 1880.
R. D. IRVING: The Copper-bearing Rocks of Lake Superior, Mon. V., U. S. Geol. Sur., p. 89, 1883.

[3] A. C. LAWSON: Report on the Lake of the Woods, Geol. and Nat. Hist. Sur. of Canada (New Ser.), Vol. I., pp. 52–3, 1885.

[4] G. H. WILLIAMS: The Greenstone-schist Areas of the Menominee and Marquette Regions of Michigan, Bull. U. S. Geol. Sur., No. 62, p. 166, Fig. 26, 1890.

[5] G. A. J. COLE and J. W. GREGORY: On the Variolitic Rocks of Mt. Genevre, Q. J. G. S., Vol. LXVI., p. 311, Fig. 4, 1890.

[6] J. W. GREGORY: On the Variolitic Diabase of the Fichtelgebirge, Q. J. G. S., Vol. LXVII., p. 48, Fig. 2, 1891.
In these last two papers the illustrations of the structure are especially characteristic.

These deposits show in places a well-developed banding caused by interbedding of layers in which coarse and fine fragments alternately prevail, illustrating well the varying intensity of the volcanic discharges. Gradation could also be traced from the coarse breccias to the delicately banded portions which are exactly analogous to the fine sand and ash beds of the modern Tertiary and recent volcanoes. These fine sand and ash beds are not, however, composed of crystal elements, but as far as the observations go are composed solely of very fine rock fragments. In such places the difference between the thickness of the ash beds and of the tuff is naturally very great. The average thickness of the ash beds observed was about three feet. In the same exposure the tuffs are from 50 to 100 feet thick. The thickness of the more massive layers could not be determined. Especially good opportunities for observing the varying relations between tuff and ash beds is offered by the third cut on the Milwaukee & Northern Railway west of Balsam, Michigan; south of the lake in Sec. 5, Township 43 N., Range 32 W., Michigan, the tuff and lava flows are very well exposed. The pyroclastics seem to predominate in the northwestern portion of the region in the neighborhood of Amasa.

It is almost needless to state that these pyroclastics have undergone a great amount of alteration, and yet the thin sections of some of the rock fragments are the freshest and prettiest seen. The changes which have taken place were purely of a metasomatic nature, and as water is the chief agent in such changes, these began in the interstices. In the case of the fragments, then, the alteration would naturally proceed from the outside inwards, and ordinarily at an equal rate all around the fragment, following its contours. In this way we get zones of different mineralogical composition, depending upon degree of alteration. This secondary zonal structure can be observed in almost any of the sections made from the breccias, but the concentric structure of many of the fragments is especially well shown on large weathered exposures.

The alterations which the fragments have undergone are the same which have taken place in the basalt and andesite flows, and the prevailing light green color of the fragments has resulted from the production of the same light colored secondary minerals. As in the lava flows, some of the denser rocks have become almost opaque, and have usually a lighter green color than the less altered fragments. An especially well preserved fragment shows the perfectly fresh feldspars lying in a dark brown isotropic glassy base. Where this is very thin, globulitic devitrification products can be seen, and there also the base is no longer isotropic, but very faintly doubly refracting.

In addition to the rock fragments a few rare ones of large plagioclase crystals were found in a tuff, and also in one case a fragment of a violet brown augite, the only specimen of fresh augite thus far found in any of the volcanics.

As was stated above, the cement is usually darker in the hand specimen than the pieces of rock imbedded in it. Under the microscope this condition is found to be reversed. The fragments as described above remain opaque or nearly so, whereas the cement becomes transparent. It is found to be composed for the most part of the same secondary minerals as occur in the fragments,—epidote, zoisite, fibrous green hornblende, chlorite, quartz, feldspar, and a great deal of brownish titanite in rounded aggregates and grains, never in crystals. Calcite is less common than one would expect, but in some cases it forms almost exclusively the cement. Muscovite is rare. Zeolites were found to be wanting in the tuffs as well as in the lavas.

The exact mode of deposit of these basaltic and andesitic breccias and tuffs, that is, whether they are true æolian deposits or are masses which were brought together by the action of water, will in some cases have to remain undecided. It is supposed that the major portion is a true æolian pyroclastic deposit.

That certain of the pyroclastics have, however, been deposited through the mediation of water is shown by specimens from 50 N., 1270 W., Sec. 34, Township 45 N., Range 33 W., near Amasa, which is a true basalt conglomerate. In these rocks the pebbles are decidedly rounded, but consist of characteristic volcanic fragments, as is shown by the amygdaloidal structure. The most of the pebbles are thoroughly impregnated with iron in the form of magnetite, giving them a black color. Under the microscope the feldspar skeletons are occupied now by chlorite and muscovite, and the portions between the skeletons is a mass of magnetite grains, in rare cases with a little hematite.

The cement is chiefly calcite and quartz in which is developed a large amount of chlorite and muscovite, and in which occurs also magnetite, though the last is more common in the fragments. No pieces of undoubted sedimentary rocks were observed in the conglomerate.

The acid volcanics.—These play a very subordinate rôle, occurring in such small quantity as to make it impossible without very great exaggeration to place them on the accompanying map. Their relations to the basic volcanics are obscured by lack of exposures, but in no case were they observed as dikes in the latter. The trend of the ridges formed by the acid rocks agrees with the general strike of the banding in the basic tuff deposits, and they are presumed to represent acid flows and tuffs interbedded with the basic lavas and pyroclastics.

On fresh fracture they are black, grading with advancing alternation into chocolate brown to reddish rocks. The weathered surface varies from white to reddish. This has in one case brought out very well the fluxion banding of the rock.

Their structure is very pronouncedly porphyritic, the quartz and feldspar crystals standing out plainly from the groundmass, which is usually dense with somewhat resinous luster. Under the microscope they are found to be typical quartz porphyries, with here and there an oval area representing amygdaloidal cavities, which are now filled with secondary quartz. The phenocrysts are for the most part corroded dihexahedral crystals of quartz, with less commonly phenocrysts of plagioclase and orthoclase. These lie in a fine grained groundmass, which is holocrystalline and composed of feldspar and quartz, with some zircon in small crystals, and here and there magnetite.

The quartzes average perhaps the size of a small pea, and hence are macroscopically quite plain. They frequently stand out on the fractures and show their crystal form, and in other cases we see the angular cavities out of which they have fallen. In the thin sections the crystal contours are seen to be more or less rounded, with here and there embayments of the groundmass projecting into them. The crystal form is, however, clearly marked. In some cases the individuals have been broken before the cooling of the magma, the fragments being seen to conform to one another. That some of them have been subjected to pressure is shown by the slight undulatory extinction and by the separation of the black cross of uniaxial minerals into hyperbolæ. The quartzes are quite clear though they contain some inclusions of groundmass and numerous liquid inclusions in which there are dancing bubbles. The liquid inclusions have very commonly an hexagonal form, corresponding to the contours of the enclosing quartz. The possession of an imperfect rhombahedral cleavage is very noticeable in a number of the quartzes, and especially those which, being on the edge of a section, are very thin. (Fig. 1.) The quartz phenocrysts in all the porphyries, with the exception of those from two localities, are surrounded by zones of varying widths, considerably lighter than the remainder of the groundmass. They have the same optical orientation as the phenocrysts, and therefore extinguish with them. In those sections in which the zones occur they are found around every quartz individual.

The feldspars present are orthoclase and plagioclase, the latter apparently predominating. They occur usually in rounded crystals, very rarely in grains with irregular more or less angular contours. They are always altered, and have associated with them the secondary products calcite, epidote, muscovite and chlorite, and by their alteration alone could be readily distinguished from the clear quartz. Moreover, the quartz and feldspar can be distinguished at a glance in certain sections by the occurrence of the aureoles around the quartz. In no case was an aureole observed to occur around a feldspar.

No ferro-magnesian minerals are found in the porphyry, nor is their former presence indicated by any secondary product. The secondary minerals contained in the porphyries are chlorite, calcite, epidote, muscovite and biotite.

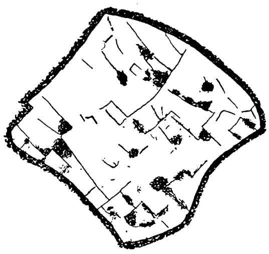

FIG. 1.— Micro-drawing of quarts, multiplied 47 diameters, showing cleavage.

The microscopic character of the dense groundmass varies according to the mode of association of its two chief elements, the quartz and feldspar, and we thus get the varieties of prophyry named after the resulting structure.

The commonest variety is the quartz-porphyry with microgranitic groundmass (Porphyre granulitique of Michel-Lévy). A second variety is the quartz prophyry with micropoikilitic[1] groundmass. The microgranitic structure is too well known to warrant a description of it here. The micropoikilitic structure which is present in the porphyries seems, however, to be a phase which is somewhat different from any thus far described or figured, and therefore deserves to be described more at length.

[1] J. P. IDDINGS: The Eruptive Rocks of Electric Peak and Sepulchre Mountain. 12th Ann. Rep. U. S. G. S., p. 589.

G. H. WILLIAMS: On the Use of the Terms Poikilitic and Micropoikilitic in Petrography. Journ. of Geol., Vol. I., No. 2, pp. 176–9. Feb.–Mar., 1892.

It is hoped that an opportunity for working this up more in detail will present itself in the near future. In the meantime I shall rely on the following brief description, and more especially upon the accompanying photographs (Pl. II., Figs. 1 and 2), to give a correct idea at least of the appearance of it under the microscope.

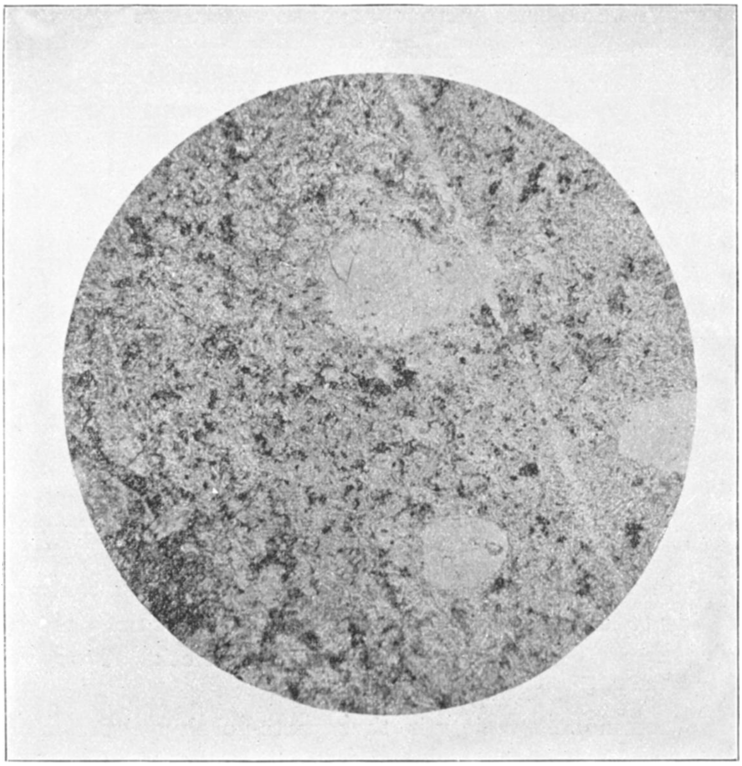

PLATE II.

FIG. 1.—Micropoikilitic quartz-porphyry, showing the peculiar structure of the groundmass in ordinary light. Magnified 18 diameters.

The structure of the groundmass can be seen even in ordinary light; it is brought out better when the field is partly shaded, so as to bring out the varying relief of the minerals (Pl. II., Fig. 1); and best of all between crossed nicols (Pl. II., Fig. 2). The groundmass is then seen to be made up of reticulating areas of clear quartz, in which lie imbedded irregular pieces of feldspar. The quartz occurs in irregular areas, extending in all directions in long slender or short broad portions, these extensions jointing again farther on or being connected by crosspieces, all enclosing irregular pieces of feldspar. The network of quartz is best brought out when it shows its highest polarization color, as then the feldspar is for the most part dark. The pieces of feldspar in such a quartz area do not all have the same orientation, as is shown by the varying extinction angle, though a goodly number do extinguish simultaneously. The boundaries between the quartz areas, which can only be seen between crossed nicols, are bridged over in some instances by the pieces of feldspar. The main point is that the quartz is the base, the feldspar imbedded in it, and that in those uniformly polarizing quartz areas the included feldspar pieces show varying optical orientation. Therefore, the structure is not a true micropegmatite, according to the generally accepted definition.

Around the porphyritic quartzes there is a zone having exactly the same structure as the groundmass, and the connection of the quartz of the crystal and that of the zone is well shown by the continuation of the quartz with it, and the consequent agreement in orientation (Pl. II., Fig. 2). The lack of a uniform optical orientation of the feldspar fragments is made especially apparent when the quartz is cut perpendicular to the c axis, and consequently remains dark between crossed nicols. Under the above circumstances we see certain feldspar grains polarizing in the zone around the quartz, and as the stage revolves new fragments lighten as those which polarized in the previous position of the stage become dark. The feldspar seems to have no effect upon the groundmass. It certainly is never surrounded by zones, as is the quartz. An explanation for these micropoikilitic zones should, then, also explain the structure of the groundmass.

The irregular areas in the groundmass are certainly in some cases, and probably in most cases, the result of tangential sections through one of these micropoikilitic zones surrounding the quartz phenocrysts. The micropoikilitic structure has been held in some cases to be of secondary origin.[1] I can find, however, no evidence whatsoever which indicates a secondary origin for the structure in these rocks. On the other hand, there is likewise an absence of evidence proving unquestionably its primary character. Rather, however, than accept an explanation which

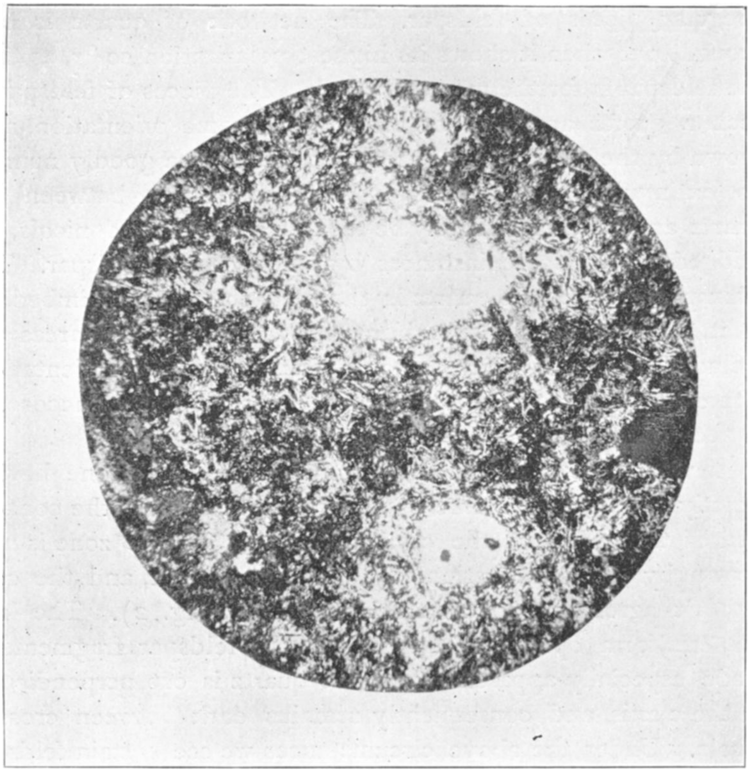

PLATE II.

FIG. 2.—The same section in polarized light, showing the micropoikilitic zone around the quartz phenocrysts. The irregular small dark spots in the white network of quartz are the feldspar grains. Magnified 18 diameters.

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[1] R. D. IRVING: The Copper-bearing Rocks of Lake Superior. Mon. V., U. S G. S., p. 99, 1883.

F. BASCOM: Structures, Origin and Nomenclature of the Acid Volcanic Rocks of South Mountain. JOURN. OF GEOL., Vol. I., No. 8, p. 816. Nov.–Dec., 1893.

requires the production of secondary quartz and the influencing of it by the phenocrysts—similar to the frequently described oriented enlargements of quartz grains in sandstones and quartzites—it seems more natural to suppose that after the crystallization of the phenocrysts when the lava was extruded, there began a rapid crystallization of the mineral elements from the remaining magma, resulting in the production of the feldspar in very imperfect crystal individuals, with the quartz as a cement, the orientation of the latter being determined by the quartz phenocrysts. In other words, the quartz continued to grow, retaining its previous orientation, its continuity interrupted, however, by the feldspar grains.

Aporhyolites.—Intimately associated with the above described quartz-porphyries we find rocks very similar in every way to them macro- and microscopically, as far as the mineral constituents are concerned, so that the description of the quartz-porphyries will answer for the aporhyolites. It is only upon the presence of a well-developed perlitic parting, which is taken as indicating the presence of an original glass, that they are classed with the rhyolites. These perlitic cracks are now well brought out in ordinary light by the chlorite flakes found along them. Between crossed nicols these disappear and the groundmass resolves itself into a fine-grained mosaic of quartz and feldspar.

Tuffs.—The only acid tuff found is formed from the rhyolite. On its weathered surface it is white and exceedingly rough. This roughness is due to great extent to the weathering and subsequent leaching out of the feldspar, giving the rock an almost scoriaceous appearance. Its brecciated character is admirably shown by the difference in weathering of the fragments and cement. The latter being very siliceous is more resistant than the rhyolite, and stands out from the rock as white ridges marking the outlines of the fragments. Under the microscope in ordinary light the tuff is seen to be composed of angular fragments of rhyolite, in which is a well developed perlitic parting, and of angular pieces of quartz and feldspar, both orthoclase and plagioclase, held together by a cement of quartz.

Conclusions.—It will be seen from the foregoing preliminary description of the volcanic rocks of the Michigamme district, that in this district we find well preserved evidence of true volcanic activity, in the presence of amygdaloidal lava flows and volcanic breccias and tuffs. These are comparable in every way in their external appearance to the ejectamenta of Tertiary and recent volcanoes. Like these, also, the rocks vary from very basic (basalts) to those containing a high percentage of silica (rhyolites).

That they have undergone more or less alteration as a result of their age alone was to be expected, but it is remarkable that in spite of their age and the dynamic action to which they must also have been exposed—since we now find the flows on edge—they should remain so fresh and retain so perfectly their characteristics as volcanic rocks. The age of these deposits has been determined to be Huronian.

This adds one more to the localities in America in which the occurrence of associated basic and acid volcanics of pre-Cambrian age have been described microscopically.[1]

That such pre-Cambrian volcanics are by no means rare in

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[1] M. E. WADSWORTH: Notes on the Min. and Pet. of Boston and Vicinity. Proc. Bos. Soc., Nat. Hist., Vol. XIX., pp. 217–237. 1877. Geology of the Iron and Copper District. Bull. Mus. Comp. Zoöl., Vol. VII. (Geol. Ser. 1), No. 1, p. 157. 1880. Did not observe the felsitic porphyries interbedded with the basic rock on Keweenaw Point, and described later by Irving, but described the conglomerates made up of trachytic and rhyolitic fragments (p. 120).

J. S. DILLER: The Felsites and their Associated Rocks North of Boston. Bull. Mus. Comp. Zoöl., Vol. VII. (Geol. Ser. 1), No. 2; and Proc. Boston Soc. Nat. Hist., Vol. XX., pp. 355–368. January 1880.

R. D. IRVING: The Copper-bearing Rocks of Lake Superior. Mon. V., U. S. G. S. 1883.

ANDREW C. LAWSON: Report on the Geology of the Lake of the Woods Region. Geol. and Nat. Hist. Sur. of Can. (New Ser.), Vol. I., CC. 1885; and Geology of the Rainy Lake Region. Geol. Sur. of Can., 1887–8, F., p. 182.

E. HAWORTH: A contribution to the Archean Geol. of Missouri. Am. Geol., Vol. I., pp. 280–297, 363–382. 1888.

T. G. BONNEY: Notes on a part of the Huronian Series in the Neighborhood of Sudbury, Can. Q. J. G. S., Vol. XLIV., pp. 32–45. 1888.

G. H. WILLIAMS: In Bell: On the Sudbury Mining District. Geol. Sur. of Can., 1890–1, F. App. L, pp. 55–82. The Greenstone-schist Areas of the Menominee and Marquette Regions of Mich. Bull. 62, U. S. G. S., 1890. The Volcanic Rocks of South Mountain in Pennsylvania and Maryland. Am. Journ. of Sci., 3d Ser., Vol. XLIV., pp. 482–496. December 1892.

America can be seen by referring to the brief reports of their occurrence in the Eastern townships of Quebec and in New Brunswick and Nova Scotia, which have been made by Bailey,[1] Ells,[2] Fletcher,[3] Matthew,[4] Selwyn,[5] and Low.[6]

Similar areas are known in Newfoundland, especially from the peninsula of Avalon, through the reports of Howley,[7] Jukes,[8] and Murray.[9]

Somewhat younger are the acid and basic volcanics described by Shaler[10] from Maine, Matthew[11] from New Brunswick, and Bayley[12] from North Haven, Maine.

Basic volcanics alone of Huronian age have been described from the Penokee area, Wisconsin, by C. R. Van Hise,[13] and to judge from Bell's[14] reports, occur in considerable quantity to the north of Lake Huron and around the shores of Hudson's Bay.

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[1] Can. G. S., 1870-1, pp. 13-240; 1877-8, DD.; 1878-9, D.; Proc. Am. Asso. Adv. Sci., 29th meeting, 1880, pp. 415-421.

[2] Can. G. S., Vol. II., J., New Ser., 1886; 1882-4, E.; 1879-80, D.; 1877-8, D.; 1878-9, D.

[3] Can. G. S., Vol. II., P., New Ser., 1886.

[4] Can. G. S., Vol. II., Rep. 3, pp. 387-391, 2d Ser., 1888. Q. J. G. S., London, Vol. XXI., pp. 422-434, 1865. Can. G. S., 1870-1, pp. 13-240; 1878-9, D.

[5] Proc. and Trans. Royal Soc. of Can. for 1882-3, Vol. I., Sec. 4, pp. 1-13.

[6] Can. G. S., 1882-4, F.

[7] G. S. of Newfoundland for the year 1881, pp. 6-23.

[8] Ibid., 1839-40, pp. 160.

[9] Ibid., pp. 111-136. G. S. 1872, pp. 279-297.

[10] Prel. Rep. on the Geol. of Cobscook Bay. Am. Journ. Sci., 3d Ser., Vol. XXXII., p. 40. 1886. Geol. of Mount Desert. Ann. Rep. U. S. G. S., Vol. VII., p. 1042. 1889.

[11] Rep. on the Upper Silurian and Kingston (Huronian) of Southern New Brunswick. Geol. Sur. of Can., Rep. 1877-8 E.

[12] The Spherulitic Volcanic Rocks of North Haven, Maine. Bull. Geol. Soc. of Am. Vol. VI., 1894, p. 474.

[13] IRVING AND VAN HISE: Penokee Iron-bearing Series of Michigan and Wisconsin. Mon. 19, U. S. G. S., p. 410. 1892.

[14] Can. G. S., Reps. for 1876-7, p. 213; 1877-8 C.; 1779-80 C. The Geol. and Economic Minerals of Hudson's Bay and Northern Canada. Proc. and Trans. Royal Soc. Can., Vol. II., Sec. 4, p. 241. 1884.]

Wadsworth[1] has also described basic volcanics from Newfoundland, and Walcott[2] has mentioned their occurrence in the Algonkian of the Grand Canyon series, stating that according to Iddings' examination they are true doleritic basalts.[3]

The volcanics of the Michigamme district can be closely paralleled with similar rocks in Finland and Sweden, described in detail with full recognition of their volcanic origin by J. J. Sederholm[4] and by Otto Nordenskjöld.[5]

Numerous descriptions of such occurrences have appeared within the past years from the English geologists,[6] and all of them have recognized in full their identity with the younger volcanics, and have usually applied the names in use for the younger to their older equivalents. Wadsworth[7] was the first in America to follow and advocate this simplification of the nomenclature. In 1892, Williams'[8] article upon the South Mountain Volcanics appeared.

In all other countries the generally accepted nomenclature has been a dual one, one term for a pre-Tertiary rock and another for its post-Tertiary equivalent,—in spite, too, of the fact that the great resemblance between such rocks has been frequently emphasized.

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[1] Notes on the Rocks and Ore Deposits in the Vicinity of Notre Dame Bay, Newfoundland. Am. Jour. Sci., 3d Ser., Vol. XXXIII., pp. 94–104. 1884.

[2] Algonkian Rocks of the Grand Canyon of the Colorado. JOUR. GEOL., Vol. III., No. 3, p. 325, April–May, 1895.

[3] Loc. cit., p. 330.

[4] Studien über Archæische Eruptivgesteine aus dem Südwestlischen Finland, Tsch. Min. and Pet., Mitt. XII., pp. 98–142. 1891.

[5] Über Basische Ergussgesteine aus dem Elfdalener Porphyrgebiet. Bull. Geol. Inst. Univ. of Upsala, Vol. I., No. 2, pp. 105–112. 1893. Über Archæische Ergussgesteine aus Småland. Ibid., pp. 133–255.

[6] For references to their papers see GEIKIE: Anniversary Address, Q. J. G. S., Vols. 47 and 48, 1891–2. Most of their papers are to be found in the files of the Q. J. G. S. and Geol. Mag. and Memoirs of Geol. Sur. of Great Britain.

[7] Notes on the Min. and Pet. of Boston and Vicinity. Proc. Bos. Soc. Nat. Hist., Vol. 19, p. 236, 1877; ibid. 1878, pp. 309–316.

On the Classification of Rocks. Bull. Mus. Comp. Zoöl., Vol. V., No. 13, pp. 275–287. 1879.

Geol. of the Iron and Copper Districts. Bull. Mus. Comp. Zoöl., Vol. VII., Geol. Ser., No. 1, p. 157, 1880.

Prel. Descr. of the Peridotites, Gabbros, Diabases, and Andesites of Minn. Geol. and Nat. Hist. Sur. of Minn., Bull. No. 2, 1887.

[8] Am. Jour. Sci., 3d Ser., Vol. XLIV., p. 486. 1892.

In a paper published in 1893, upon the acid rocks of the region described in the preliminary paper by Williams,[1] Miss Bascom[2] proposes "to call the acid volcanic rocks whose structures prove them to have once been glassy, *aporhyolites*, while those which have consolidated at a sufficient depth to secure a holocrystalline groundmass should be termed *quartz-porphyries*, whether ancient or modern lavas," the moment which is to determine the use of the name being the "specific alteration known as devitrification." Thus, using the term rhyolite in its present sense, extended however so as to include its pre-Tertiary equivalents, we may have rhyolites of all ages, and likewise aporhyolites of all ages. It was proposed also to apply the prefix *apo* to all other devitrified rocks.

Independently of Miss Bascom, and shortly after her paper appeared, Nordenskjöld proposed, before the Students' Association of Natural Science of the University of Upsala,[3] the names *eorhyolite*, *eobasalt*, etc., for the old equivalents of the rocks known as rhyolites, basalts, etc. It appears to me preferable to use the nomenclature proposed by Miss Bascom, both on the grounds of priority and of expressiveness, as the name indicates in what condition we will find the rocks, whereas the names proposed by Nordenskjöld would merely mean an addition to petrographical literature of new names to express conditions which are already expressed by names at present in use. Thus under eorhyolites we have rocks placed in opposition to the neorhyolites, which as a result of their age are probably very much altered, though this condition is not necessary for the correct application of the term as I understand it. It is possible that at some time there may be found an insignificantly altered rock which must be classed with the eorhyolites. On the other hand, we will undoubtedly find rocks which are apo- but not eorhyolites. Moreover, the idea of time is inseparably connected with the names proposed by Nordenskjöld, and it is very desirable to eliminate this altogether from petrographical nomenclature. Again, unless there is to be a decided gain from the use of new terms, we might just as well continue to use the terms which have been so long in use, as felsite, etc., as these already imply a difference in age and condition of preservation. According to Miss Bascom, we can consistently class devitrified rocks, whether pre-Cambrian or recent, under aporhyolites and apobasalts, and their fresh equivalents likewise, whether pre-Cambrian or recent, under the accepted term rhyolite, basalt, etc.

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[1] Loc cit.

[2] The Structures, Origin, and Nomenclature of the Acid Volcanic Rocks of South Mountain. JOUR. OF GEOL., Vol. I., No. 8, p. 829. Nov.-Dec., 1893.

[3] Loc. cit., p. 292, meeting on November 18, 1893.

J. MORGAN CLEMENTS.

MADISON, WIS.,
May 29, 1895.